micrOMEGAs: recent developments

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Abstract

The program `micrOMEGAs` that calculates the relic density of the lightest supersymmetric particle (LSP) in the MSSM is presented. The impact of coannihilation channels and of higher order corrections to Higgs widths is stressed. The dependence on the RGE code used to calculate the soft parameters is also discussed.

1 Introduction

The measurements of the relic density of cold dark matter (CDM) have provided stringent constraints on the parameters of the R-parity conserving mininal supersymmetric standard model (MSSM). Hence a large effort has been devoted to the calculation of the relic density in the MSSM, and many private and public programs have been developed [1]−[7]. Here we present `micrOMEGAs`, a program that is publicly available [6]. To make predictions for the relic density of CDM at the few percent level, special care must be taken to treat carefully the case where annihilation via a s-channel resonance can occur as well as the case of coannihilations where the LSP interacts with slightly heavier sparticles.

The calculation of the relic density necessitates the evaluation of a thermally averaged cross-section. The proper relativistic formalism for treating this was introduced in Ref. 8 and proved to be essential when annihilation through s-channel pole is important. The generalization of this formalism to the case of coannihilations [9], was implemented in the codes of Refs. 2-3, for the case of gaugino coannihilations. We follow basically this formalism.

Coannihilation processes where the LSP interacts with slightly heavier sparticles can occur in principle with any supersymmetric particle [10], although in SUGRA models, the most common coannihilations are with gauginos [11, 9], right-handed sleptons [12, 13] or stops [14]. In micrOMEGAs we include *ALL* coannihilation channels, in all more than 2800 processes not counting charged conjugate processes. The tree-level cross-sections are calculated exactly including the full set of diagrams contributing to each process. The calculations of the cross-sections are based on `CompHEP`[16]. Furthermore we include also some higher order effects, namely the two-loop corrections to the Higgs mass [17] and the one-loop QCD corrections to the Higgs width [18]. The latter turns out to be particularly important in the large $tan\beta$ region with the enhanced coupling of the Higgs to b quarks.

After the important equations for the calculation of the relic density are summarized, we give a short description of the package. We present some results and comparisons with other programs emphasizing the role of coannihilations and Higgs poles. Finally we discuss the impact of the choice of the RGE code in SUGRA models on the relic density.

2 Calculation of the relic density

The calculation of the relic density at present necessitates solving the evolution equation for the relic abundance, Y

$$\frac{dY}{dT} = \sqrt{\frac{\pi g_*(T)}{45G}} < \sigma v > (Y^2 - Y_{eq}^2) \tag{1}$$

where Y_{eq} represents the thermal equilibrium abundance. This equation depends on $< \sigma v >$, the relativistic thermally averaged annihilation cross-section, which involves a sum over σ_{ij} , the total cross section for annihilation of a pair of supersymmetric particles into Standard Model particles.

$$< \sigma v >= \frac{\sum\limits_{i,j} g_i g_j \int\limits_{(m_i+m_j)^2} ds \sqrt{s} K_1(\sqrt{s}/T) p_{ij}^2 \sigma_{ij}(s)}{2T(\sum\limits_i g_i m_i^2 K_2(m_i/T))^2} \, , \tag{2}$$

The total number of processes involving two SUSY particles into two SM particles exceeds 2800. In practice, processes involving the heavier SUSY particles contribute only when there is a near mass degeneracy with the LSP due to a strong Boltzmann suppression factor. To speed up the program a given subprocess is removed from the sum (2) if the total mass of the incoming particles is below a value defined by the user, typically $\approx 2.5 m_{\tilde{\chi}_1^0}$.

Rather than solving for Y numerically, which is extremely time consuming especially when we include a great number of processes, we follow the usual procedure of defining a freeze-out temperature T_f [8]. This approach differs from the one in `DarkSusy`[6].

3 Description of `micrOMEGAs`

`micrOMEGAs` is a C program that also calls some external FORTRAN functions. `micrOMEGAs` relies on `CompHEP` [16] for the definition of the parameters and the evaluation of all cross-sections. Only a small fraction of the available processes are needed for a given model, those with a sparticle close in mass to the LSP. To restrict the size of the program, we include in our package the program `CompHEP`[16] which generates, while running, the subprocesses needed for a given set of MSSM parameters. The generated code is linked during the run to the main program and executed.

The model file used by CompHEP is obtained via LanHEP [19], a program that generates the complete set of particles and vertices once given a Lagrangian. In the model used, the Higgs masses are calculated at two-loop with `FeynHiggsFast` [17]. Higher order QCD corrections to the Higgs widths are incorporated by extracting, from HDECAY [18], effective quark masses $m_q(m_H)$ which are then included in the $Hq\overline{q}$ vertices.

In `micrOMEGAs`, there are two options for the input parameters: either the soft parameters of the supersymmetric Lagrangian at the weak scale or the parameters of a SUGRA-type model at the GUT scale. In Version 1.1.1, the latter option is made available via a link to `Isajet`. However, the next upgrade will include links to other codes, namely `SuSpect` and `SoftSusy`, as will be discussed in the last section.

After the calculation of the relic density is performed, the list of channels that give the most significant contribution to Ωh^2 are given. We also provide subroutines that calculate various constraints on the MSSM parameters: direct limits from colliders, $b \to s\gamma$ and $(g-2)_\mu$.

4 Results and Comparisons

The micrOMEGAs code was extensively tested against another public package for calculating the relic density, DarkSUSY. The two codes differ somewhat in the numerical method used for solving the density equations, in the number of channels included (all subprocesses in micrOMEGAs) and in the use of loop-corrected Higgs widths [2]. Whenever the coannihilation channels with sfermions and the Higgs pole are not important we find good agreement with DarkSUSY [3]. However, when non gaugino coannihilations are important, we find that the impact of the extra channels can be as large as two order of magnitude and depends critically on the mass difference with the lightest neutralino. Due to the large cross-sections in channels involving strongly interacting particles, the effect of coannihilation is particularly striking when the NLSP is a squark (Fig. 1a).

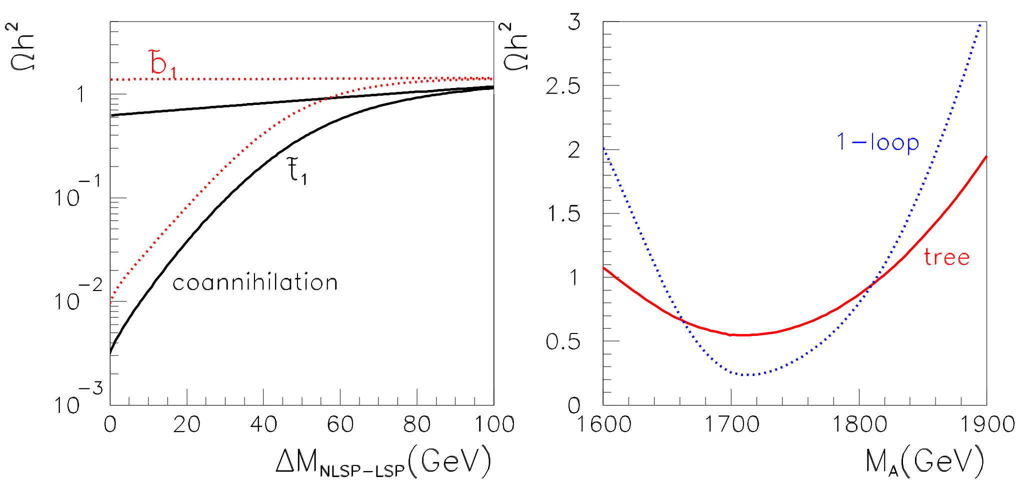

Figure 1: a)Ωh^2 vs the NLSP-LSP mass difference with $m_{\tilde{u_R}}(m_{\tilde{d_R}})$ as a free parameter including coannihilation(full) and without coannihilation(dash). The NLSP is the $\tilde{t}_1$ ($\tilde{b}_1$). The parameters are the ones of Model F; b)Comparison of tree-level/one-loop treatment of Higgs width. Ωh^2 vs m_A, $\tan\beta = 45$, other parameters are the ones of Model E.

Near a heavy Higgs resonance, we also observe differences with DarkSusy, these disappear if we switch to the tree-level width option. The effect of the Higgs width is particularly important at large $\tan\beta$ with the enhanced contribution of the b-quark coupling to the heavy scalar Higgs. One-loop QCD corrections which reduce the Higgs width especially at large values of m_H can change Ωh^2 by as much as a factor 2 (Fig. 1b).

In the case of SUGRA models, we find qualitative agreement with Ref. [24] particularly for small values of $\tan\beta$. Significant differences are found at large $\tan\beta$. This can be due to the RGE code used to calculate the soft parameters at the weak scale, as will be discussed next.

[2] Sfermions coannihilations will be included in upgrades of DarkSusy[23].

[3] Complete agreement between micrOMEGAs and an improved version of DarkSusy including slepton coannihilation channels was found recently in Ref. [22].

5 RGE code and relic density

To determine the influence on the RGE code used to determine the soft MSSM parameters on the calculation of the relic density, we have compared three of the most widely used RGE codes: `Isajet`, `SuSpect` and `SoftSusy`. The parameters that we expect might influence significantly the value of the relic density are μ which determines the gaugino fraction, m_A which is relevant when neutralino annihilation occurs near the Higgs s-channel pole and finally the NLSP-LSP mass difference.

In the notoriously difficult large $\tan\beta$ region, significant differences in the value of m_A [25] can lead up to factors of two differences in the relic density (Fig. 2). At large M_0, the relic density calculated in `Isajet` can be two orders of magnitude below that in the other two codes due to a significantly lower value for the parameter μ [25] (leading to a large increase in the $\tilde{\chi}_1^0\tilde{\chi}_1^0 \to W^+W^-$ cross-section). Finally in the coannihilation regions, the relic density can vary by an order of magniture even though the differences between the codes can be rather small (a few Gev's). This occurs at large $M_{1/2}$ and/or large A_0 where the $\tilde{\tau}$ is the NLSP (Fig. 2) [26]. In general rather good agreement is found between `SoftSusy` and `SuSpect`, whereas larger differences can be observed with `Isajet`.

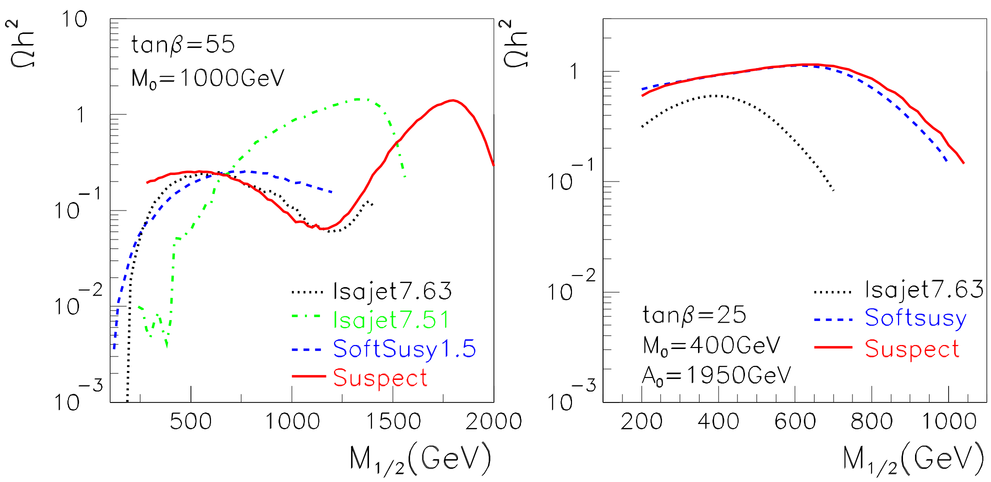

Figure 2: Comparison of `Isajet`, `SoftSusy` and `SuSpect`, Ωh^2 vs $m_{1/2}$ in a SUGRA model with $\mu > 0$ and $m_{top} = 175$GeV a) $\tan\beta = 55$ b) $\tan\beta = 25, A_0 = 1950$GeV.

6 Conclusion

The package `micrOMEGAs` that allows to calculate the relic density of the LSP in the MSSM is the first program that includes all possible coannihilation channels. Loop corrections to the masses and widths of Higgs particles are implemented. Good agreement with existing calculations is found when identical channels are included and higher order corrections are removed.

The next upgrade of `micrOMEGAs` will include more links to programs for calculating RGE, (`SoftSusy` and `SuSpect`) as well as new improved routine to $b \to s\gamma$. Progress has also been made towards including new models beyond the MSSM, such as the nMSSM, and additonal modules for calculating constraints on the MSSM such as $B_s \to \mu^+\mu^-$ will be available.

Acknowledgments

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